Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Incidence of the Mechanical Properties of Adobe Reinforced with Sheep Wool and Hydrated Lime in the C.P. Cacray-Huarochirí 2023

Peña Vargas, Karen Lizbeth, Mg. Ing. Reynoso Oscanoa, Javier

Universidad César Vallejo (Perú)
Email: kpenav@ucvvirtual.edu.pe

The present thesis entitled "Incidence of the mechanical properties of adobe reinforced with sheep wool and hydrated lime in C.P. Cacray-Huarochirí 2023" had the general objective of establishing the incidence of the reinforcement with sheep wool and hydrated lime on the mechanical properties of adobe in C.P. Cacray-Huarochirí, 2023. The research employed a hypothetical deductive method, explanatory level, quantitative approach, applied type with quasi-experimental design, used in a census sample comprising 20 cubes of soil for compressive strength, 20 cylindrical specimens; for indirect traction and 12 piles of adobe; for axial compression of soil reinforced with the addition of sheep wool at 0%, 3%, 6% and 9% percentages and hydrated lime at 1% percentage. The appropriate proportions for making adobes were determined, obtaining 4 designs. The results indicated that the optimum amount of sheep wool was 9% and hydrated lime 1%, presenting a resistance to compression 13.94 kg/cm2, traction 2.88 kg/cm2 and axial compression in piles 8.26 kg/cm2. Therefore, it was concluded that the reinforcement of sheep wool and hydrated lime has a positive effect on the mechanical properties of adobe in C.P. Cacray-Huarochirí, 2023.

Keywords: Adobe, sheep wool, hydrated lime, strength, tensile, compression.

1. Introduction

Internationally, currently, between 30% and 50% of the world's population lives in adobe houses, especially in Africa, Asia and Latin America, while in Europe they remain a niche of the construction industry. One of the elements that have been considered to be the most interesting in earthen construction is the use of sun-dried earth bricks - made of raw clay earth mixed with straw or fibre (the so-called "adobe"), as a cladding material. Where the main raw materials used are coarse sand, clay soil and lime and lime. Natural soil mixtures are usually corrected by adding fibers, to control cracking while the adobes dry in the sun, but these techniques lead to problems because they are not adequate, thus generating damage to homes in the long and short term (Statuto et. al. 2018, p.597). Likewise, half of the inhabitants of underdeveloped countries; of which 80% is rural population and the remaining urban and suburban, resides in adobe houses, so its great structural vulnerability has attracted the attention and concern of numerous researchers, in search of analyzing the behavior of adobe houses in seismic events, as well as the mechanical properties of adobe, since there are no standards for their tests on walls (Catalán et. al. 2019, p.2).

At the national level, the population uses adobe in the construction of their homes to generate the comfort that is required due to the intense cold because the climatic phenomena impact the southern high Andean area in Puno, Arequipa and Cusco, causing that at night the low temperatures in the environments drop near or below 0°C. which constitutes a problem that affects the inhabitants, causing various damages, particularly to the health of the most vulnerable, including children and the elderly (Holguino, Olivera, & Escobar, 2018, p.290).

In the same way, according to Sandoval (2018, p.22), the El Niño phenomenon caused great physical devastation, particularly in the north of the country, where entire cities were buried by rocks, rubble and the murky currents of overflowing rivers, which also destroyed traditional domestic structures. According to INDECI reports, this phenomenon caused 162 deaths, 500 injuries and 19 missing. It also left 28,000 homes uninhabitable, severely damaged and collapsed.

At the local level, in Cacray, Huarochiri, according to the latest warning (No. 079) issued by Senamhi, there was a warning about the possible activation of streams in the near future in the red and orange alert areas of the provinces of Lima (Oyón, Huaura, Yauyos and Huarochirí) and Metropolitan Lima. Likewise, the rains caused by the weather phenomenon weakened most adobe homes, so it was warned that more than 8,000 people are at risk of possible damage to their homes due to the possible excess of rainfall (above its normal pattern) forecast for April to June 2023 (León, 2023, p.3).

At the international level, there were precedents such as that of Atbir et. al. (2023), who carried out an article called "Study of the physicochemical and thermomechanical properties of Timahdite fibers for their application in building insulation", carried out in India, aimed to thermomechanically characterize solid unfired bricks based on clay (white and red) and Timahdite sheep's wool, which are local materials, durable, abundant and economical. Their methodology was experimental and consisted of incorporating sheep's wool in the form of multilayers of yarn in opposite directions to achieve good thermal and mechanical performance and a lightness of these bricks as a progress acquired. The results showed that the effect of the wool yarn was optimal, showing a flexural strength of 18 to 56% for white clay and 8 to 29% for red, decreasing compression from 9 to 36% for white clay and from 5 to 18% for red. These mechanical performances are accompanied by a gain in thermal conductivity ranging from 4 to 41% for white clay and from 6 to 39% for red clay for wool fractions. In conclusion, the multilayer bricks from abundant local materials and with optimal thermomechanical properties, were suitable for the intended use of thermal insulation and energy efficiency in the construction and development of local economies.

Similarly, in Colombia, Silva et. al. (2019), in their article entitled "Optimization of compressive strength using a mixture design of extreme vertices, in ternary concretes based on hydrated lime and masonry residue" aimed to examine the use of ternary mixtures that are cement, masonry residue and hydrated lime to optimize concrete. Using an experimental methodology through the development of an extreme vertex mixture design and the use of residues and lime as substitutes for the cementitious material (up to 20% by weight), the properties in the fresh and hardened state were evaluated. The results were that compression was greater when there was a higher percentage of residue substitution and a lower percentage of hydrated lime.

Likewise, in Morocco Atbir et. al. (2023), in their article entitled "Thermodynamic analysis of a multilayer brick of sheep's wool yarn and clay grids" they set out to develop a multilayer brick based on clay and thin layers of a network of sheep's wool yarns, the researchers used an experimental methodology by performing the physical-chemical characterization of the clay used using the DRX Powder methods, MEB-EDX, as well as the thermal characterization of composite materials based on the number of layers inserted into the clay using the asymmetrical hot plate, hot wire methods. Obtaining as results, after comparison, the values of the samples with different compositions present significant experimental results for thermal conductivity, diffusivity and effusivity compositions in the order of λ = 0.33 to 0.36 W.m-1. $^{K-1}$, E = 710 to 657J.m-2.K-1.s-$1^{/2}$ and A = 2.58 to 1.81 m2.s-1, respectively, these characteristics are better. Likewise, in the gradation, the fineness modulus obtained values from 4 to 5.24. This allowed us to conclude that a significant improvement in the insulating properties of the composite materials developed is shown.

In India, Alyousef et. al. (2019), carried out an article called "Use of sheep fleece as a potential fibrous material in the production of concrete composites", with the objective of investigating the use of sheep's wool fibers in the production of reinforced concrete through the analysis of strengths and microstructural characteristics. The methodology was experimental, they made eight concrete mixtures containing 0-6% normal sheep's wool fibers with a length of 70 mm. In addition, four concrete mixtures were made with modified sheep's wool fibers of 0-1.5% with the same length. The results were that the addition of so much wool reduced the settling values of fresh concrete. The incorporation of these fibers in the concrete mixtures reduced the compressive strength, however, it subsequently improved the tensile strength and flexural values, thus optimizing the ductility of the concrete with a higher energy absorption capacity. The microstructural characteristics of sheep's wool reinforced concrete showed good adhesion and a low level of voids. Where they concluded that the addition of the fibers in the concrete is adequate, technically and environmentally.

Similarly, in India, Alyousef et. al. (2019), carried out an article called "Influence of wool on the properties in the fresh and hardened state of fiber-reinforced concrete", with the aim of investigating the properties of concrete with sheep's wool fibers. Its methodology was quasi-experimental, testing a total of sixty cylindrical specimens and prisms. Obtaining as results; in the tensile tests (whose maximum value was 3.5 MPa) and compression (whose maximum value was 25 MPa), allowed to meet the objective of the study. Traction was improved by adding fibers with high strength and the crack bridging effect of the smooth and elastic fibers was worked to improve the ductility and bending capacity of the concrete. It was concluded that the reduction of compressive strength due to such fibers in concrete can be minimized by appropriate treatment, which should be investigated accordingly.

Finally, Ahmad and Rehman (2021), in their article entitled "Experimental research on the use of sheep fleece as a fibre reinforcement in concrete, with the consequent increase in the overall strength of the material", carried out in India, applied the objective of evaluating the properties of concrete after adding sheep fibre to it, their methodology was experimental, for which they made concrete specimens and tested them. The results showed that sheep's wool fiber showed an approximate 21.1% increase in flexural strength, 28.7% tensile strength and 12% compressive strength. In conclusion, using sheep's wool by immersing it in salt water as an additive, it can withstand more compression and bending compared to ordinary Portland cement concrete.

At the national level, there are precedents such as that of Muñoz et. al. (2021), in Chiclayo, in their article entitled "Review of the compressive strength of concrete incorporating varieties of fiber additions", where they proposed as an objective to review the aforementioned topic, using the non-experimental design methodology and the documentary review technique of 50 indexed articles from the last 10 years, made up of: 18 Scopus articles, 13 ScienceDirect articles and 17 Scielo articles, illustrating the effects of various types of fibers on concrete. According to the results, sheep's wool reduced compressive strength, the workability of the mixtures and on the contrary improved the flexural strength. It was concluded that the optimal amounts of addition in the concrete ranged from 2-3% unadulterated sheep's wool to 0.5-0.1% modified sheep's wool.

Likewise, in Lima, Ramírez (2017), in his master's thesis entitled "Study of the mechanical and physical properties of adobe with biopolymers from local sources", aimed to investigate the improvement of absorption, suction and mechanical responses of adobe, using experimental methodology, for this, natural biopolymers from the place were used. The soil samples treated with polymeric solutions were subjected to permeability and erosion experiments to determine their resistance to water by applying various techniques for the administration of the solutions. The result was that it was possible to positively alter the behavior of the soil. Concluding that there was a notable improvement in resistance.

On the other hand, in Puno, Holguino, Olivera, and Escobar (2018), in their article called "Thermal comfort in an adobe room with heat storage system in the Andes of Peru", they set out to analyze the thermal comfort inside the test room built with adobe, using an experimental design and applied research type. in which adobe (earth and straw), plaster and wood were built, and specimens of 12x12x1.8 cm3 were made for each of them. Therefore, thermal conductivity values of 0.176 W/mK for adobe, 0.149 W/mK in gypsum and 0.118 W/mK in wood were determined in the results.

Finally, in Lima, Laban, Clemente, and Choque (2023), in their article called "Resistance of concrete with incorporation of sugarcane fibers and wood charcoal ash", where the objective of analyzing how the addition of sugarcane fibers and coal ash, whose origin is organic waste, influences the influence of the which will be incorporated into the concrete mix, using an experimental design and applied research type, where the dosage of fibers was replaced with respect to the weight of fine aggregate, while the percentages of ash were substituted with respect to the weight of the cement, in order to determine the optimal strength. The result was that the design with the best performance contained 0.5% fibers and 2.5% ash, obtaining a f'c of 336.93 kg/cm2 (20.33% higher than that of the control sample) and a diametrical tensile strength of 30.33 kg/cm2 with a percentage of 78.43%, which represented a decrease of 21.57%. The conclusion was that resistance is affected the greater the presence of additives, in particular fiber.

The present project was justified in a practical way because it offered a solution to the problem of the manufacture of stabilized adobe because, by using sheep's wool fiber and hydrated lime in the adobe, its mechanical resistance improved to be able to withstand dynamic loads; such as wind and earthquakes and statics; such as the live and dead loads typical of construction. Theoretically, it was justified because it was deepened to validate knowledge of both the independent variable such as sheep's wool fiber and hydrated lime, as well as the dependent variable; which is the mechanical properties of adobes, because the mechanical properties of adobe, because the mechanical properties of adobe. It was methodologically justified because it proposed a new method of manufacturing the mixtures for adobe by adding fiber and lime in order to stabilize the adobe and make it more resistant and, therefore, more durable. As a social justification, a contribution to civil engineering was generated since a new procedure for the manufacture of these adobes was announced, from the design of mixtures that is where the fibers were added to give flexibility and hydrated lime to stabilize the concrete.

The general objective was to establish the incidence of reinforcement with sheep's wool and hydrated lime on the mechanical properties of adobe in C.P. Cacray-Huarochirí, 2023. The specific objectives were the following: To determine the incidence of the incorporation of sheep's wool and hydrated lime in the resistance to the understanding of adobe. To establish the incidence of the incorporation of sheep's wool and hydrated lime on the indirect tensile strength of adobe. To verify the incidence of the addition of sheep's wool and hydrated lime on the axial compressive strength of the adobe.

2. METHOD

2.1 Type and design of research

The present research was of an applied type, because various knowledge was used regarding sheep's wool and hydrated lime and its interaction with adobe to optimize its mechanical properties, which were verified by compressive stress tests in cubes, axial in piles and diagonal in adobe walls.

The design to be used was experimental and the sub-design was quasi-experimental, because only the independent variable that is sheep's wool and hydrated lime was manipulated to evaluate its impact on the dependent variable that is constituted by the mechanical properties of adobe.

2.2 Variables and operationalization

The independent variable (1) is sheep's wool.

The independent variable (2) is hydrated lime.

The dependent variable is the mechanical properties of adobe.

2.2.1 Conceptual definition

VI (1): According to Cáceres (2021), sheep's wool fiber is a dermal material, likewise, it is divided by hair follicle and has an outer layer that is flaky and water-repellent.

VI (2): Paytán and Perez (2018) pointed out that hydrated lime is produced through the calcination and subsequent hydration of limestone containing clays (silica and alumina). In addition to calcium hydroxide, there are also silicates and calcium aluminates in its composition.

VD: The mechanical properties of adobe represent its behavior under the action of stresses, so these properties are parameterized with compression values of 10.2 kg/cm2 or more, flexion of f't= 2.6 kg/cm2 to 3 kg/cm2, and traction of 0.81 kg/cm2 (Standard E080, 2017).

2.2.2 Operational definition

VI (1): Sheep's wool fiber was added in percentages of 0%, 3%, 6% and 9% depending on the weight of the mixture to make the adobe.

VI (2): The hydrated lime was added in a percentage of 1% depending on the weight of the mixture to make the adobe.

VD: The analysis of the mechanical properties of the adobe was carried out by means of the tests of compressive strength of the adobe, indirect traction of the adobe and axial compression in adobe piles according to NTE 080.

Indicators

VI (1): Density

VI (1): Humidity

VI (1): Dimension

VI (1): Addition 0.0%

VI (1): Addition 3.0%

VI (1): Addition 6.0%

VI (1): Addition 9%

VI (2): Density

VI (2): Humidity

VI (2): Chemical Analysis

VI(2): Addition 1%

2.3 Population, sample and unit of analysis

The unit of analysis was represented by 20 cubes for the compression test of 10 cm of edge (Figure 1).

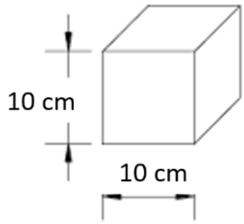

Figure 1. Cube Dimensions

Source: Authors.

For the indirect tensile test, 20 cylindrical specimens of 15.24 cm x 30.48 cm (6" x 12") in diameter and length were fabricated as shown in Figure 2.

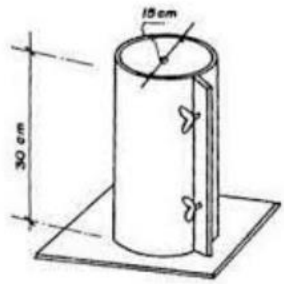

Figure 2. Dimensions of the cylindrical specimen.

Source: https://goo.su/Qnz9L

In addition, for the axial compression test, the unit of analysis was 12 piles of 20cmx40x38cm composed of 4 adobes of dimensions 20x40x8 cm. Figure 11 shows the basin made up of 4 adobes, where the height (h) measures 38cm, the width (a) 20cm and the length (b) 40cm.

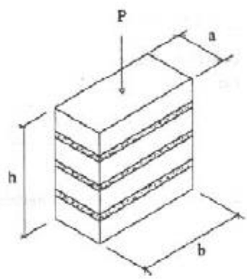

Figure 3. Pile Dimensions

Source: NTE 080 (2017).

2.4 Data collection techniques and instruments

The technique to be used was direct observation because through this it was possible to see the changes in the characteristics of the adobes, when they are subjected to the experiments and it was seen whether or not they comply with the increase in their design values. In addition, documentary analysis was used, since the search for bibliographic databases composed of articles from indexed journals, master's and doctoral theses was deepened to conform the structure of the theoretical framework and methodology.

The instruments were the laboratory test formats, through which the necessary data were collected for the tests of granulometry (ASTM D6913), moisture content (ASTM C566 19), loose and compact unit weight (NTP 400-017), liquid and plastic limit (ASTM D4318), dry resistance (NTE 080), compression in reinforced earth cubes (NTE 080), indirect traction in cylindrical reinforced earth specimens (NTE 080) and axial compression in piles (NTE 080).

2.5. Procedure

The procedure consisted of:

First stage (cabinet); Bibliographic sources were compiled from scientific articles belonging to indexed journals, national and international regulations (updated), master's and doctoral theses, books, among others. The quarry where the aggregates were purchased and the places where the purchase of sheep's wool fiber and hydrated lime was made was identified. Likewise, the place where the earth was extracted to manufacture the adobe was identified. The tests to be carried out were determined, and then the laboratory accredited by INACAL was searched and located, and the data record sheets for the respective tests were made.

Second stage (field); Sheep's wool fiber was purchased from the Village of Cacray – Huarochirí, then the impurities were removed by immersing the wool in hot salt water, and then putting them to dry by hanging them in a clean and dry place. Subsequently, the sheep's wool was brushed to remove the lumps of wool, carefully so as not to alter its internal structure and reserved to be taken to the laboratory. The hydrated lime was purchased and the sieving was done using the #200 mesh. Then, the soil was extracted in better conditions from the Ayarbalto Quarry located in the Cacray Village Center belonging to the district of San Mateo de Huanchor that belongs to Huarochirí. The material was then sent to the Centauro Ingenieros Soil Laboratory located in the city of Huancayo in the department of Junín.

Third stage (laboratory); The sheep's wool fiber and hydrated lime were taken to the UNALM laboratory, where the analysis of its chemical composition and the analysis of the physical composition of the sheep's wool fiber was carried out with respect to the specific thickness, density and absorption of sheep's wool, to verify that its components are adequate according to the E080 standard.

Tests were carried out to find out the quality of the soil with which the adobe was manufactured. For which, in the first place, the granulometry test was carried out, where at first the container where the sieves were ordered from 3" to number 200, including the bottom, was weighed and the sieving began by sifting the sieves to weigh the sample retained in each sieve, and then, Calculate the percentage of pesos withheld and passers-by. The data from the particle size analysis were also used to make soil classifications using the SUCS and ASSHTO Method.

Then the liquid limit test was carried out and, with the results of the liquid and plastic limit, the plasticity index could be determined. Next, the moisture content test was done. Finally, the weight of the dry soil, the weight of the water and the percentage of moisture were calculated.

The dry resistance of the soil was tested, for which four balls were first formed in the palms of the hands and little water so that the balls would not deform too much when drying. This procedure was done repeatedly until the necessary water was calculated and a proportion of water was extracted. Then, the pellets were left to dry, protected from moisture, for 48 hours. The balls were then pressed firmly between the thumb and index finger. With which it was verified that none of the balls broke, so it was verified that the earth can be used to make adobes. On the other hand, the roll test was done, where a roll was made with the moistened floor, moving it with the index finger and thumb, from which it was verified that the roll broke between 10 and 20 cm, verifying that the soil is suitable for making the masonry units.

The mixture for the adobes was designed, obtaining the appropriate proportions of the materials made up of earth, water, sheep's wool fiber to give it the due tensile strength and hydrated lime to stabilize the adobe and thus give it greater compressive strength. Where the proportions of for the 4 designs were defined.

Regarding the preparation of the mixture, first the total soil comprising 1 m3 was mixed, and combined with 1 cylinder and a half of water (300 liters), with the help of a shovel it was stirred well until a uniform mixture was achieved. Immediately afterwards, the lime corresponding to 1% of the weight of the total soil was added, after that the mixture was separated into four parts that corresponded to the 4 designs and then the sheep's wool fiber was incorporated into each of the mixtures in percentages of 3%, 6% and 9% with respect to the weight of the soil. respectively. Then, each of the mixture designs was labeled to identify them and the mixtures were left to rest for 4 hours, to proceed with the manufacture of the specimens.

The wooden molds were made to pour the mixture, with measurements of 10 cm in edge for the compression cubes, the molds for the adobes of 6" x 12", and, regarding the specimens, the standard size for the concrete were used.

20 buckets were made by pouring the mixture into the 10 cm edge molds. The 20 cylindrical specimens were manufactured in molds measuring 15.24 cm x 30.48 cm (6" x 12") in diameter and length. Then, the 80 adobe units were manufactured in 20x40x8 cm molds, for the subsequent manufacture of the 20 piles. The cubes, test tubes and adobes were dried in the sun and in the open air with a protection so that the sun does not hit them directly and in a dry climate. It should be noted that due to the fact that the area has constant rains, a plastic was prepared to wrap and put in a safe place to protect the adobes when such a case happened.

Finally, compressive strength tests were carried out at the age of 28 days after the adobes were manufactured, where first, it was clear that the average of the 5 samples for each design exceeds the ultimate resistance of 10.2 kg/cm2. During the test, the load was applied perpendicular to the contact area of the cubes and the maximum load was recorded, to later determine the compressive strength by means of a formula. Then the indirect tensile test by diametric compression was carried out on the specimens after 28 days, where it was made sure that the average of the 5 samples tested per dosage exceeds the value of 0.81 kg/cm2, then the specimens were subjected by applying the load axially, recording the ultimate resistances in all the samples. Finally, the axial compression test was performed at 20 piles, at the age of 28 days, for which the measurements of the contact area in each of the samples were first taken, then they were subjected to load and the last forces were recorded, verifying that they exceed the ultimate resistance of 6.12 kg/cm2.

Fourth stage (Cabinet); With the results obtained, the analysis was carried out, hypotheses were tested and conclusions, discussions and final recommendations of the research project were made.

3. RESULTS

3.1 Selection of materials for adobe

- Soil

Sections (a) and (b) show the results of the on-site tests, and sections (c), (d) and (e) show the results of the laboratory tests, which were carried out to determine the quality of the soil.

a) Dry Strength Test

Table 1. Dry Strength Test

Characterization	Sample N°1	Sample N°2	Sample N°3
At least 1 pellet breaks and/or cracks	NO	YES	YES
No pellets break or crack	YES	NO	NO
Evaluation	SUITABLE	NOT FIT	NOT FIT

Interpretation: It can be seen in Table 1 that in samples 2 and 3, the test balls break or crack, so they are discarded because they are part of a soil not suitable for the manufacture of adobes. Sample No. 1 was chosen, because it contains the most suitable soil as it presents better resistance characteristics and complies with the E 080 Standard that establishes it as optimal.

b) Mud Tape Test

Table 2. Mud Tape Test

Characterization	Sample N°1	Sample N°2	Sample N°3
The roll has a length of 5 cm	NO	YES	NO
The roll has a length that is between 10 and 20 cm	YES	NO	NO
The roll has a length greater than 20 cm	NO	NO	YES
Evaluation	SUITABLE	NOT FIT	NOT FIT

Interpretation: It can be seen in Table 2 that in samples N°2 and N°3, the rolls have a very small and very large length, respectively, so they were discarded in the selection of the soil because they were not suitable. Sample No. 1 was chosen, because it contains the soil suitable for presenting an optimal clay content and complying with the E 080 Standard that establishes it as optimal.

3.2 Aggregate results

c) Soil moisture content.

Table 3. Moisture content result

POLL	Sample	Sample Type	Moisture Percentage	Drying Method
Ayarbalto Quarry	M-1	Soil	11	110°C +-5
Ayarbalto Quarry	M-2	Soil	11	110°C +-5
Ayarbalto Quarry	M-3	Soil	11	110°C +-5

Interpretation: According to Table 3, the moisture content is 11%, which is why it complies with the standard. Likewise, this value was taken into account for the elaboration of the adobes since it had to be controlled that it has less than 20% weight of water in the dry state, verifying that the least amount of water is used.

d) Atterberg Boundaries

Table 4. Atterberg Limits Result

Atterberg Boundaries			
Samples	Sample N°1	Sample N°2	Sample N°3
Liquid limit	36	36	36
Plastic limit	15	15	15
Plasticity Index	21	20	20

Interpretation: According to Table 4, it can be deduced that the material of the three samples is a plastic floor since the value of the plasticity index is greater than 0. Therefore, for a complete evaluation of the suitability of a soil for the manufacture of adobe, its other properties must be considered.

e) Soil granulometry

Table 5. Soil particle size analysis

Sieve	Opening	Percentage that passes (%)		
N°	(mm)	M-1	M-2	M-3
3"	75	100	100	100
2"	50	100	100	100
1 1/2"	37.5	100	100	100
1”	25	100	100	100
3/4"	19	100	100	100
3/8"	9.5	98.1	99.8	98.1
4	4.75	96.6	98.4	96.6
10	2	95.2	97	95.2

20	0.85	93.5	95.3	93.5
40	0.425	91.7	93.6	91.7
60	0.25	90.3	92.3	90.3
140	0.106	88.7	90.7	88.7
200	0.075	88.4	90.5	88.4

Interpretation: From the wing Table 5, it can be seen that the maximum size is 3/4" and the maximum nominal size is 3/8". In addition, the percentage that passes mesh No. 4 is almost 100% and more than 12% passes mesh No. 200 (88.4%). Therefore, it is a suitable soil for the manufacture of adobes.

- Water

Drinking water was used, verifying that it was clean, free of contaminants such as organic matter, heavy metals and other contaminants that could affect the quality of the adobe. In addition, it was free of suspended solids because they can affect the quality and appearance of the adobe.

- Hydrated lime

Table 6. Physicochemical properties of hydrated lime

Physical and chemical properties	
Aspect	Dust
Colour	White
Smell	Odorless
Ignition	Incombustible
Flammability	Non-flammable
Explosiveness	Non-explosive
Contact with water	Exothermic reaction

In table 6 you can see the properties of hydrated lime, you can also see that it is a non-combustible material so when used in the adobes it will give security against any flammable event that occurs inside the house in which these masonry units will be used.

Table 7. Chemical Composition of Hydrated Lime

Chemical Composition	
Calcium hydroxide Ca(OH)2 (Total)	85%
Calcium Hydroxide Ca(OH)2 (Available)	83%
Magnesium Oxide MgO	0.70%
SiO2 silica	1%
Insoluble in HCl	1.50%
H2O Humidity	1%

From Table 7, it can be seen that lime is a binding material and that it meets the chemical composition to qualify as hydrated lime, so it will be ideal for adhesion between the internal particles of the adobe.

- Sheep's wool

Figure 4. Sheep's wool.

The sheep's wool was obtained by cleaning, brushing to detangle it and washing it with salt water, and then obtaining the clean wool, as shown in Figure 4.

Table 8. Physical properties of sheep's wool

Sheep's wool fibre	Wick length (cm)	Fiber Diameter	
		Diam. Prom (microns)	Desv. Standard (microns)
Sample 1	8.22	25.90	5.00
Sample 2	8.40	28.00	5.60

According to the results shown in Table 8, the length of the wicks was 8.22cm and 8.40cm. On the other hand, when recording the diameters in the specialized equipment S-Fiber EC V3.1, a diameter of 25.90 microns was obtained for sample No. 1 and 28.00 microns for sample No. 2, with standard deviations of 5 and 5.60 microns, respectively. From which an average length of 8.31 cm and an average diameter of 26.95 microns was obtained.

3.3 Compressive strength results

The results of the compressive strength tests on cubes are presented in Table 16.

Table 9. Compressive Strength

Test group	Percentage of hydrated lime	Percentage of sheep's wool	Compressive strength f'o (kg/cm2)
GC	0%	0%	12.40
GE-1	1%	3%	13.62
GE-2	1%	6%	13.86
GE-3	1%	9%	13.94

Table 9 shows that the control group and experimental groups 1, 2 and 3 had values of 12.40, 13.62, 13.86, 13.94 kg/cm2, respectively. Therefore, GE-1, GE-2 and GE-3 increased by 9.84%, 11.77% and 12.42%, respectively compared to GC. In addition, the highest f'o value was presented by the GE-3, verifying that it is the optimal sample since it presented the best behavior with the addition of 9% sheep's wool and 1% hydrated lime.

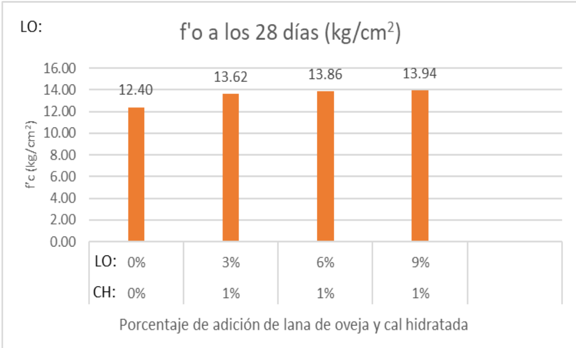

Figure 5. Graph of percentage of hydrated lime and sheep's wool vs f'o.

In the bar graph of Figure 5, it can be seen that, when hydrated lime and sheep's wool are added, the resistance increases, that is, they have a directly proportional relationship, so it is verified that these additions improve the compressive strength, so that the adobe will withstand being subjected to greater loads with the contribution of these natural additives.

Table 10. Percentage of compressive strength obtained

Percentage of added hydrated lime	Percentage of addition of sheep's wool	% of Compressive Strength at design f'o=10.2 kg/cm2 obtained
0%	0%	21.57%
1%	3%	33.53%
1%	6%	35.88%
1%	9%	36.67%

Interpretation: From Table 10, it can be seen that all the percentages obtained were greater than the design resistance. The GC, GE-1, GE-2 and GE-3, had higher percentages in 21.57%, 33.53%, 35.88% and 36.67%, respectively, in relation to the design resistance specified for an adobe whose value was 10.2 kg/cm2, for which it is affirmed that all the test units complied with the E080 standard, exceeding the minimum resistance.

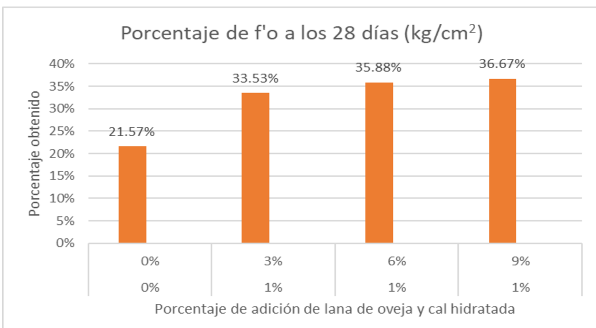

Figure 6. Graph of percentage of compressive strength obtained.

In Figure 24, it is interpreted that, when hydrated lime and sheep's wool are added in percentage increments, the percentage of resistance obtained increases, that is, they are directly related, so it is verified that these additions are better than the compressive strength of the design, so that the adobe can be subjected to greater loads than the design as the incorporation of wool is increased and with 1% hydrated lime.

3.4 Tensile strength results

The results of the tensile strength tests on specimens are presented in Table 18.

Table 11. Tensile strength

Test group	Percentage of hydrated lime	Percentage of sheep's wool	Tensile strength (kg/cm2)
GC	0%	0%	2.09
GE-1	1%	3%	2.38
GE-2	1%	6%	2.86
GE-3	1%	9%	2.88

Table 11 shows that the control group and experimental groups 1, 2 and 3 had values of 2.09, 2.38, 2.86, 2.88 kg/cm2, respectively. Therefore, GE-1, GE-2 and GE-3 increased by 14%, 37% and 38%, respectively compared to GC. In addition, the highest tensile value was presented by the GE-3, verifying that it is the optimal sample since it presented the best behavior with the addition of 1% hydrated lime and 9% sheep's wool.

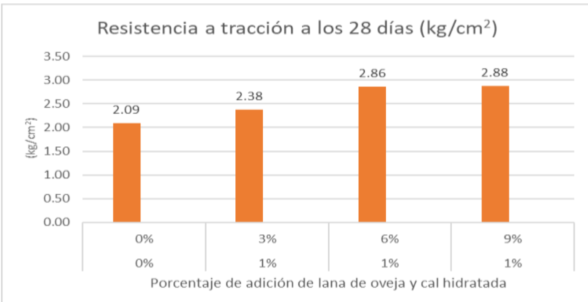

Figure 7. Graph of percentage of additions vs tensile strength.

In the bar graph in Figure 7, it can be seen that, when hydrated lime and sheep's wool are added, the resistance increases, that is, they have a directly proportional relationship, so it is verified that these additions improve the tensile strength.

Table 12. Percentage of tensile strength obtained

Percentage of added hydrated lime	Percentage of addition of sheep's wool	% of Design Tensile Strength 0.81 kg/cm2 obtained
0%	0%	157.78%
1%	3%	193.58%
1%	6%	253.33%
1%	9%	255.56%

Table 12 shows that the control group and experimental groups 1, 2 and 3 increased by 157.78%, 193.58%, 253.33% and 255.56%, respectively, compared to the design tensile strength (0.81 kg/cm2). In addition, the maximum tensile strength value was presented by the

GE-3, verifying that it is the optimal sample since it presented the best behavior with the addition of hydrated lime and sheep's wool.

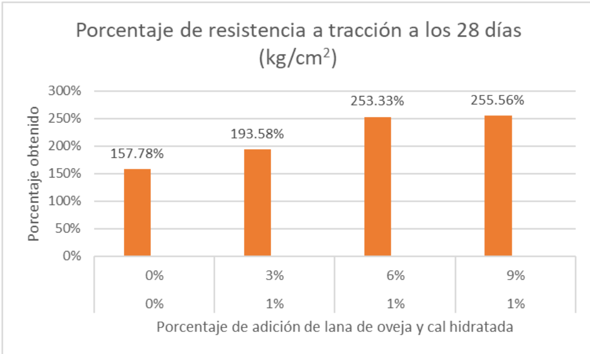

Figure 8. Graph of percentage of tensile strength obtained.

In Figure 8, it is interpreted that, by adding sheep's wool in percentage increments and hydrated lime at 1%, the percentage of tensile strength obtained increases, that is, they are directly related, so it is verified that these additions are better than the compressive strength of design, so that the adobe can be subjected to greater loads.

3.5 Results of axial compressive strength in piles

The results of the axial compressive strength tests on piles are presented in Table 13.

Table 13. Axial compressive strength in piles

Test group	Percentage of hydrated lime	Percentage of sheep's wool	Compressive strength f'm (kg/cm2)
GC	0%	0%	8.24
GE-1	1%	3%	9.34
GE-2	1%	6%	8.52
GE-3	1%	9%	8.26

Table 13 shows that the control group and experimental groups 1, 2 and 3 had values of 8.24, 9.34, 8.52, 8.26 kg/cm2, respectively. Therefore, GE-1, GE-2 and GE-3 increased by 13.35%, 3.40% and 0.24%, respectively, compared to GC. In addition, the highest value of f'm was presented by the GE-1, verifying that it is the optimal sample since it presented the best behavior with the addition of 3% sheep's wool and 1% hydrated lime.

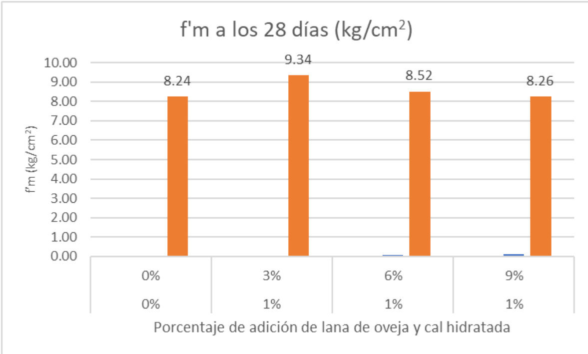

Figure 9. Graph of percentage of additions vs resistance in piles

In the bar graph in Figure 9, it can be seen that, when the additions are made, the resistance increases to the maximum point of 9.34 kg/cm2, that is, they have a directly proportional relationship, with 3% sheep's wool and 1% hydrated lime. However, additions with 6% and 9% sheep's wool decreased progressively, which shows that the optimal percentage occurred with the first addition.

Table 14. Percentage of compressive strength obtained in piles

Percentage of added hydrated lime	Percentage of addition of sheep's wool	% of compressive strength at design f'm=6.12 kg/cm2 obtained
0%	0%	34.64%
1%	3%	52.61%
1%	6%	39.22%
1%	9%	34.97%

Table 14 shows that the control group and experimental groups 1, 2 and 3 increased by 34.64%, 52.61%, 39.22% and 34.97%, respectively, compared to the design f'm (6.12 kg/cm2). therefore, it is stated that all the test units complied with the E080 standard, exceeding the minimum resistance. In addition, the maximum value of axial compressive strength in piles was presented by the GE-1, verifying that it is the optimal sample since it presented the best behavior with the addition of hydrated lime and sheep's wool, in relation to the design resistance.

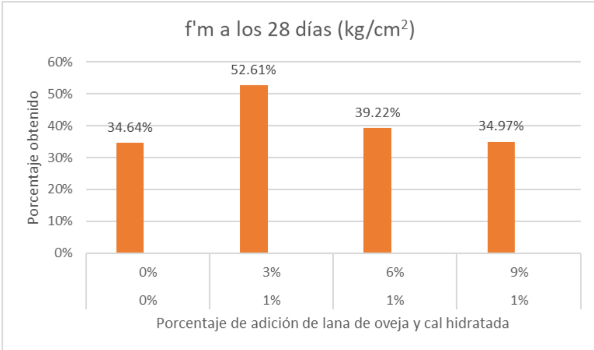

Figure 10. Graph of percentage of compressive strength in piles obtained.

Figure 10 shows the increasing behavior of the percentage of axial compressive strength in piles obtained up to 3% addition, which is where it begins to decrease, with the first addition showing the inflection point where the maximum value of this property occurs. However, all the samples have exceeded the value of the design strength, so it is verified that these additions are better than the design compressive strength, so that the adobe can be subjected to greater loads than it.

4. DISCUSSION

The present research was carried out with the aim of establishing the incidence of reinforcement with sheep's wool and hydrated lime on the mechanical properties of adobe in C.P. Cacray - Huarochirí, 2023, for which an experimental study design has been used, through which laboratory tests were carried out with additions of sheep's wool in percentages of 0%, 3%, 6% and 9% and hydrated lime at 1%, depending on the weight of the mixture to make the adobe.

Regarding specific objective 1, which consisted of determining the incidence of the incorporation of sheep's wool and hydrated lime in the resistance to adobe compression, it was found that the experimental groups with 3%, 6% and 9% of sheep's wool and 1% of hydrated lime increased their resistances by 9.84%, 11.77% and 12.42%. respectively compared to the control group. Therefore, when the additions are made, the resistance increases, that is, they have a directly proportional relationship, so it is verified that these additions improve the compressive strength, so that the adobe will withstand being subjected to greater loads with the contribution of these natural additives. On the other hand, it was found that experimental groups 1, 2 and 3 had higher percentages in 21.57%, 33.53%, 35.88% and 36.67%, respectively, in relation to the design resistance specified for an adobe whose value was 10.2 kg/cm2, for which it was stated that all the test units complied with the E080 standard, when exceeding the minimum resistance. In addition, the highest value of f'c was presented by experimental group 3, verifying that it is the optimal sample since it presented the best behavior with the addition of 9% of sheep's wool and 1% of hydrated lime.

In addition, in the statistical analysis, it was found that the data were distributed normally, which is why the ANOVA test was used, the p value of all groups was 0.0174, being lower than the significance of 0.05, therefore, the alternate hypothesis (H1) was approved and the null hypothesis (H0) was rejected. In other words, there was sufficient evidence to support the original assertion that the incorporation of sheep's wool and hydrated lime favorably affects the resistance to understanding of adobe.

When making comparisons with the results of the research of Atbir et. al. (2023), who, by incorporating sheep's wool in the form of multilayers of yarn in opposite directions to achieve good performance and mechanical as acquired progress, obtained that the additions were optimal, showing an increase in compression from 9 to 36% for white clay brick and from 5 to 18% for red clay brick. This is similar to the results of the present research because as the sheep's wool fibers were incorporated, the resistance increased, improving their mechanical behavior. On the contrary, the percentages of increase were lower since they varied between 10% and 13% increase compared to the standard adobe.

When comparing the results of this work with those of the article by Alyousef et. al. (2019), who used sheep's wool fibers in the production of reinforced concrete, the compressive strength was reduced showing a maximum value of 51 kg/cm2, however, the values of tensile strength and flexural subsequently improved, so he concluded that the reduction of the compressive strength can be minimized by appropriate treatment, which should be investigated accordingly. In contrast, with the present additions, increases in compressive strength were shown, due to the fact that an optimal cleaning of the fiber was made in NaCl and boiled water and in addition, a stabilization with hydrated lime was made, which contributed to optimize the mechanical property itself.

For Ahmad and Rehman (2021), who incorporated sheep fleece as a fiber reinforcement in the concrete, they showed that sheep's wool fiber showed an approximate 12% increase in compressive strength, which is why they verified that, using sheep's wool by immersing it in salt water as an additive, it can withstand more compression compared to ordinary Portland cement concrete. With which it is agreed that the addition of this natural material increased said mechanical resistance, so it is verified that doing the same process of submergence for cleaning contributes to its improvement. In addition, the increase in the percentage of resistance present was very close (12.42%) to the previous study.

In relation to specific objective 2, to establish the incidence of the incorporation of sheep's wool and hydrated lime in the diagonal tensile strength of adobe, it was found that experimental groups 1, 2 and 3 increased by 14%, 37% and 38%, respectively compared to the control group. In addition, the maximum tensile strength was presented by the GE-3, verifying that it is the optimal sample since it presented the best behavior with the addition of 1% hydrated lime and 9% sheep's wool. Likewise, when hydrated lime and sheep's wool are added, the resistance increases, i.e. they have a directly proportional relationship, so it is proven that these additions improve the tensile strength. It was also found that experimental groups 1, 2 and 3 increased by 157.78%, 193.58%, 253.33% and 255.56%, respectively, compared to the design tensile strength (0.81 kg/cm2), which is why the adobe can be subjected to greater loads.

Finally, statistically, the finding was that the data were normal and according to ANOVA, the significances were less than 0.05. Therefore, according to the decision rule, H1 was approved and H0 was rejected. In other words, the original assertion that the incorporation of sheep's wool and hydrated lime significantly affects the tensile strength of adobe was approved.

When comparing the results of the present work with those of the article by Ahmad and Rehman (2021), who used sheep fleece as a fiber reinforcement in the concrete, they showed that the sheep's wool fiber showed an approximate increase of 28.7% in traction, so they determined that, with sheep's wool, the concrete withstood more traction compared to engineered concrete. Therefore, we agree with these results, since the behavior of the fiber-reinforced adobe improved significantly and gradually while the additions were made. However, it differs in that the optimal percentage significantly exceeded the design resistance (0.81 kg/cm2) by 255.56%, which shows that the present results are better than the previous study.

Comparisons were made with the results of the research of Laban, Clemente and Choque (2023), who by incorporating sugarcane fibers and wood charcoal ash into the concrete, obtained as a result that the design with the best performance contained 0.5% fibers and 2.5% ashes, obtained a diametrical tensile strength of 30.33 kg/cm2, which meant a decrease of 21.57%, so his conclusion was that resistance is affected the greater the presence of additives, in particular fiber. This is different from the present results because as the natural material was incorporated, the tensile strengths increased reaching a 38% increase, depending on the standard sample.

Regarding specific objective 3, which consisted of verifying the effects of the addition of sheep's wool and hydrated lime on the axial compressive strength of adobe, it was found that experimental groups 1, 2 and 3 increased by 13.35%, 3.40% and 0.24%, respectively, compared to the standard sample, that is, the resistance increases to the maximum point of 9.34 kg/cm2, therefore, they have a directly proportional relationship, with 3% sheep's wool and 1% hydrated lime. However, piles with additions with 6% and 9% sheep's wool progressively decreased. In addition, the highest value of f'm was presented by the first addition, verifying that it is the optimal sample since it presented the best behavior with the addition of 3% sheep's wool and 1% hydrated lime. On the other hand, it was found that the control group and experimental groups 1, 2 and 3 increased by 34.64%, 52.61%, 39.22% and 34.97%, respectively, compared to the design f'm (6.12 kg/cm2). therefore, all the test units complied with the E080 standard, exceeding the minimum resistance.

In addition, according to the statistical analysis, all data were distributed normally and with the use of the ANOVA parametric test, it was found that the significances were greater than 0.05. Therefore, according to the decision rule, H1 was approved and H0 was rejected. That is, the original assertion that the addition of sheep's wool and hydrated lime has significant effects on the axial compressive strength of the adobe is correct.

In addition, the results were compared with those of the research by Silva et. al. (2019), who examined the use of ternary mixtures using residues and lime as substitutes for the cementitious material (up to 20% by weight), obtained as results that the traction was greater when there was a higher percentage of waste substitution and a lower percentage of hydrated lime. Therefore, they are dissimilar, since the amount of lime used is far from that of the previous work, being a percentage of 1%, however, an increase of 14% was observed compared to the control sample.

Then, the results were compared with those of the study by Muñoz et. al. (2021), that, according to the results, sheep's wool reduced the compressive strength, the workability of the mixtures and on the contrary improved the flexural strength, for which they concluded that the optimal amounts of addition ranged from 2-3% of unadulterated sheep's wool to 0.5-0.1% of modified sheep's wool. This is relevant to the present study, since the optimal percentage of addition to improve axial compressive strength in piles was also 3%, which can be attributed to the quality of the mortar used.

That said, the present research had limitations regarding the addition of sheep's wool, because, when incorporating it in higher percentages, a drop in the compressive strength properties was observed, which is why the design was changed to lower percentages of addition, to find the maximum point (9%) where the properties presented optimal results.

On the other hand, strengths were observed, with respect to the analysis of results, because due to the fact that we worked with 5 samples for each of the percentages in each trial, a total sample of 20 cubes, 20 specimens and 80 adobe piles was obtained, with which an efficient statistical analysis could be carried out, it was possible to validate the results by contrasting the hypotheses with parametric tests and thus approving the hypotheses raised. In addition, there was accessibility to the material made up of sheep's wool fiber since its quantity resulted in the Village of Cacray, since it was a material that was not used because it was waste that was discarded after the wool was manufactured, due to the process of unraveling and washing that had to be given.

Finally, the contribution lay in the fact that, with the results of this research, it is feasible to make improvements in the properties of the adobes to guarantee their optimal behavior and that the future house in which they will be used is durable, since the addition used shows a significant increase in mechanical resistance.

5. CONCLUSIONS

1. It was concluded that the incidence of reinforcement with sheep's wool and hydrated lime on the mechanical properties of adobe in C.P. Cacray-Huarochiri, 2023, due to the fact that all groups increased their resistances compared to the control group, exceeding the design resistances of the E080 standard. The best percentage of addition being 9% of sheep's wool and 1% of hydrated lime with a value of 13.94 kg/cm2, 2.88 kg/cm2 and 8.26 kg/cm2 of compression, tensile and compressive strength in piles, respectively. In addition, according to the statistical analysis, the data were distributed normally, obtaining with Anova a significance of less than 0.05, so the alternative hypothesis was accepted and the null hypothesis was rejected.

2. It was determined that the incorporation of sheep's wool and hydrated lime favorably affects the resistance to adobe compression, since the experimental groups with 3%, 6% and 9% of sheep's wool and 1% of hydrated lime increased their resistance by 9.84%, 11.77% and 12.42%, respectively compared to the control group and had higher percentages in 21.57%. 33.53%, 35.88% and 36.67%, respectively, in relation to the design resistance specified for an adobe whose value was 10.2 kg/cm2, for which it is affirmed that all the test units complied with the E080 standard.

3. It was established that the incorporation of sheep's wool and hydrated lime significantly affects the tensile strength of adobe, the experimental groups with 3%, 6% and 9% of sheep's wool and 1% of hydrated lime, increased by 14%, 37% and 38%, respectively compared to the control group and were higher by 157.78%. 193.58%, 253.33% and 255.56%, respectively, compared to the design tensile strength (0.81 kg/cm2), of the E080 standard. In addition, the maximum tensile strength was presented by the addition of 6%, verifying that it is the optimal sample.

4. It was determined that the addition of sheep's wool and hydrated lime has significant effects on the axial compressive strength of adobe, the control group and the experimental groups, increased by 34.64%, 52.61%, 39.22% and 34.97%, respectively, compared to the design f'm which was 6.12 kg/cm2, so all the test units complied with the E080 standard, when exceeding the minimum resistance.

References

1. ABANTO Castillo, T. F. (2018). Analysis and design of masonry buildings (2 ed.). Lima: San Marcos E.I.R.L.
2. AHMAD Wani, I., & Rehman Kumar, R. (2021, January 29). Experimental investigation on using sheep wool as fiber reinforcement in concrete giving increment in overall strength. Materials Today: Proceedings. doi:https://doi.org/10.1016/j.matpr.2020.11.938
3. ALYOUSEF, R., Alabduljabbar, H., Mohammadhosseini, H., Mustafa Mohamed, A., Siddika, A., Alrshoudi, F., & Alaskar, A. (2020). Utilization of sheep wool as potential fibrous materials in theproduction of concrete composites. Journal of Building Engineering, 30. doi:https://doi.org/10.1016/j.jobe.2020.101216
4. ASTM D4318. (2005). Standard Test Method for Liquid Limit, Plastic Limit, and Soil Plasticity Index (Vol. 20). Retrieved from https://kupdf.net/download/astm-d4318-05-limite-liquido-plastico_5d0a38f8e2b6f55c38b9520c_pdf#modals
5. ASTM D6913. (2017). Standard test methods for particle-size distribution (gradation) of soils using sieve analysis 1. Retrieved from https://doi.org/10.1520/D6913-17
6. ATBIR, A., El Wardi, F. Z., Khabbazi, A., & Cherkaoui, M. (2022, September). Thermophysical study of a multi-layer brick of grids made of sheep's wool yarn and clay. Environment and Sustainability. doi:https://doi.org/10.1063/1.5117033
7. CATALÁN Quiroz, P., Moreno Martínez, J., Galván, A., & Arroyo Matus, R. (April 10, 2019). Obtaining the mechanical properties of adobe masonry through laboratory tests. Acta universitaria, 29(e1861). Retrieved from https://www.scielo.org.mx/pdf/au/v29/2007-9621-au-29-e1861.pdf
8. CHARITHA, V., Athira, V., Jittin, V., Bahurudeen, A., & Nanthagopalan, P. (2021, May 24). Use of different agro-waste ashes in concrete for effective upcycling oflocally available resources. https://www.sciencedirect.com/science/article/abs/pii/S0950061821006115 1/8. doi:https://doi.org/10.1016/j.conbuildmat.2021.122851
9. FERNÁNDEZ d'Arlas, B. (October 15, 2019). Tough and functional cross-linked bioplastics from sheep wool keratin. Scientific Reports. Retrieved from https://www.nature.com/articles/s41598-019-51393-5
10. GALARZA Viera, J. L., Hernández Olivares, F., & Arcones Pascual, G. (2020). Stabilization of compressed earth blocks (BTC) by addition of sugarcane bagasse ash (CBCA) and calcium oxide recovered from seashells. Annals of Building, 7(1). Retrieved from http://polired.upm.es/index.php/anales_de_edificacion/article/view/4768
11. GELANA, D., Kebede, G., & Feleke, L. (2019, November 11). Investigation on Effects of

Sheep Wool fiber on Properties of C-25 Concrete. Retrieved from https://saudijournals.com/media/articles/SJCE_36_156-183.pdf

12. HOLGUINO Huarza, A., Olivera Marocho, L., & Escobar Copa, K. U. (September 2018). Thermal comfort in an adobe room with heat storage system in the Andes of Peru. Journal of High Andean Research, 20(3). Retrieved from http://www.scielo.org.pe/scielo.php?script=sci_arttext&pid=S2313-29572018000300003
13. HUAYTA, B., Inga Palacios, J., & Rodriguez Marín, C. (December 2019). Sugarcane fiber in simple concrete for sidewalks and rigid pavement. Scientific and academic writing. Retrieved from https://issuu.com/71490225/docs/fibra_de_ca_a_de_az_car_en_el_concreto_simple_para
14. LABAN Guerrero, E. A., Clemente Condori, L. J., & Choque Flores, L. (December 30, 2023). Concrete strength with the incorporation of sugarcane fibers and wood charcoal ash. Ciencia Latina Revista Científica Multidisciplinar, 6(6). doi:https://doi.org/10.37811/cl_rcm.v6i6.4188
15. LEÓN, J. (2023, March 21). Rains and landslides are now hitting Lima Provinces. La República. Retrieved from https://larepublica.pe/sociedad/2023/03/21/lluvias-en-peru-huaicos-ahora-golpean-a-lima-provincias-ciclon-yaku-1973538
16. MINISTRY of Housing, Construction and Sanitation. (2018). Construction manual: Anti-seismic adobe buildings.
17. MUÑOZ Pérez, S., Sandoval Siesquen, F., Martínez Lara, E., & Pazos Antezana, J. (February 18, 2021). Review of the compressive strength of concrete by incorporating varieties of fiber additions. Cuban Journal of Engineering, 12(1). Retrieved from https://rci.cujae.edu.cu/index.php/rci/article/view/820
18. STANDARD E080. (2017). Design and construction with reinforced earth. El Peruano. Retrieved from https://cdn-web.construccion.org/normas/rne2012/rne2006/files/titulo3/02_E/E_080.pdf
19. QUITEÑO, A. A. (March 2015). Lime as an element that improves resistance in the production of adobe bricks in the department of Ahuchapán. Research Yearbook. Retrieved from https://diyps.catolica.edu.sv/wp-content/uploads/2016/06/30CalAnVol4.pdf
20. RAMÍREZ Caparó, J. E. (2017). Study of the mechanical and physical properties of adobe with biopolymers from local sources. Thesis to opt for the degree of Master in Civil Engineering. Pontificia Universidad Católica del Perú, Lima. Retrieved from https://tesis.pucp.edu.pe/repositorio/handle/20.500.12404/12054
21. SANDOVAL Alvarado, G. D. (2018). Evaluation of erosion and resistance of adobe by adding coal ash and lime. Thesis for the professional title of Civil Engineer. Universidad Católica Santo Toribio de Mogrovejo, Chiclayo. Retrieved from http://tesis.usat.edu.pe/xmlui/handle/20.500.12423/4232
22. SILVA Urrego, Y., Rojas, J. E., Gamboa, J. A., Gordillo, M., & Delvasto, S. (June 2019). Optimization of compressive strength using a mixture design of extreme vertices, in ternary concretes based on masonry residue and hydrated lime. EIA Journal, 16(31). doi:https://doi.org/10.24050/reia.v16i31.1177
23. TARQUE, N., Crowley, H., Varum, H., & Phino, R. (2020). Structural parameters of adobe houses (Cusco, Peru) for the evaluation of seismic performance. Retrieved from https://ria.ua.pt/bitstream/10773/9473/1/D_009.pdf